Optimization of heterogeneous capacities considering the profit margin per product

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\textbf{ABSTRACT}

This paper aims to present a proposal to improve this methodology for the analysis of heterogeneous capacities based on the profit margin per product. Which was structured in three moments: development of the proposal, deployment in a business context and validation of the results through the application of a linear programming method. This proposal considers the five initial steps of the existing tools as a starting point, taking as a reference the normal time available for each homogeneous group and introducing modifications in the steps. The application of the methodology in the conditions of SMEs demonstrated its ability to generate results superior to those of traditional methods and similar to those obtained by specific linear programming techniques.

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\textbf{Introduction}

According to García Vidal (2006), the administrative sciences have evolved from different schools or approaches: Classical, Socio-psychological, Quantitative, Neoclassical and Eclectic; who have been shaping their theoretical body. Within these schools, the mathematical school is recognized, which was guided by the development of a set of techniques with mathematical foundations for the optimization and control of the quality of the productive flows. The Mathematical Theory emerged in the administration from the contributions of: Von Neumann and Morgenstern in 1947 on the Game theory, the development of the Statistical decision theory by Wald and Savage in 1954, the Decision theory by Herbert Simon and the development of computers.

The techniques and procedures for the determination of productive capacities by the general are oriented to the great industries and have been developed since the first half of the XX century. In the classical literature, there are both methods for the analysis of homogeneous productions: production of a single production nomenclature in each equipment (OIT, 1996; Niebel & Freivalds, 2001) as well as proposals for heterogeneous productions: combined use of the same equipment to produce different production nomenclatures in a given time frame (Fundora-Miranda et al., 1997). The technologies developed, under these original approaches, generally have as a limitation that they are oriented to determine the production capacity from the available time funds and the production capacities of the installed equipment, and not considering a priority system in its function. Contribution margin of each product, or if they try to find the optimal solution by means of the essay and error of the priorities.

With the evolution of technologies and mainly of computational techniques, more precise and diverse proposals have been developed that have facilitated the generation of analysis with a greater degree of precision. Adopting different names in function of its creator and its way of functioning: Genetic Algorithms (Zhang et al., 2021), Ant colony optimization algorithm (Zha & Zeng, 2013; Zheng...
et al., 2019), Particle jam (Jian-sha et al., 2009; Komalavalli & Padma, 2021), among others. These new proposals have resulted in the original or traditional procedures being relatively obsolete.

In general, most of these tools are applied to large industries and require the application of a highly qualified work force and the provision of computer technologies that facilitate their development. However, the majority of companies in the majority of countries do not respond to the described reality to apply the high technologies. According to Krishman (2017), the micro and SMEs constitute a highly significant percentage of the total number of companies. According to the report of the Organization for Economic Cooperation and Development OECD (2015), more than 99% of companies in the countries that make up the organization and the G20 are SMEs. Similar behavior is reported in the Asia-Pacific Region with between 30 and 50% of the employment coming from this sector. In the European Union, around 66% of the work places contribute to the jobs that, in the US, around 99% of the commercial companies are jobs and offer 52% of the total employment.

Several authors (Gélinas & Bigras, 2004; Barrett & Mayson, 2006) also mentioned the significant result of the micro and SMEs, the latter citing Tansky and Heneman (2003, p. 299) who have already stated that “the SMEs have been treated as second-class citizens …”. According to Gélinas and Bigras (2004), the distinctive features of the logistics of las SMEs have been analyzed since the 1970s, when Love and Gilmore published one of the first works to consider logistics as it applies to SMEs (Logistics review for the small company) (Murphy et al., 1999). In agreement with Hamta et al. (2013), “…the studies on balances of operational lines date back to 1955, the author indicates that the first scientific study on the subject was published by Salveson in 1955. Since then, different approaches have been proposed to enrich the analysis of line balances and many attempts have been made to reduce the wide gap between the academic discussion and the realistic situation…” (p. 99). In the study carried out by Zheng et al. (2019) until 2018 on the Web of Science, more than 2476 publications of investigative results aimed at optimizing productive flows were registered. These studies (Kucukkoc et al., 2018; Tanhaee et al., 2020), in general, seek to: optimize the use of installed capacities, increase productivity, decrease cycle duration, decrease volume of work places, energy consumption, environmental contamination (Kalayci & Gupta, 2014), the learning cost curve (Wu et al., 2018).

In this sense, it is necessary to point out that when some authors seek to reduce operating costs (Kazemi & Sedighi, 2013), the fundamental tendency of the objective function is oriented towards the reduction of work times or the number of jobs, assuming that there is a direct relationship between the decrease in the technological cycle and the cost, as well as there must be a direct relationship between the decrease in the cycle and the increase in productivity and income. However, it should be noted that this presumption is not always valid, given that in all cases the operations of shorter time are less expensive. Likewise, the cost variable should not be absolute as a source of profit, but more than the contribution margin of each product, based on the relationship between the price and the variable unitary cost of product, where the objective of every company. Some assume a deterministic behavior of the work times of the different operations, yet others (Hamta et al., 2013; Chiang et al., 2016) recognize a stochastic behavior of time and establish lower and upper limits of operating times.

The application of mathematics in business sciences constitutes an important branch within the administrative sciences, with the development of computer sciences and associated technologies their use, the complexity of their analysis and the quality of their results have increased. However, the use of these techniques is not within the operational and financial scope of most entrepreneurs in micro and small companies and which are constituted by most entrepreneurs in national economies. On the other hand, the traditional methods of capacity analysis do not include the profit margin per products as a fundamental variable to consider when optimizing capacities. In this research, the main objective is to present a proposal to improve this methodology for the analysis of heterogeneous capacities based on the profit margin per product.

**Research and Methodology**

**The mathematical developments to find the optimal solutions**

The mathematical developments to find the optimal solutions or the best solutions are applied to particle jamming algorithms (Şahin & Kellegöz, 2019; Sridevi & Chakkravarthy, 2021), genetic algorithms (Anel et al., 2022) or the ant colony algorithm (Lausch & Mönch, 2016; He et al., 2020); which, although they differ from each other, allow researchers to obtain the expected results. These solutions also provide more satisfactory results, demanding knowledge for their modeling and technologies that are not within the reach of a large part of the business sector, and which, if necessary, determine to optimize their productive capacities, establish if it is possible to respond to demand that imposes the market in which operations and programs are most effective in their productive flows. In this sense, the most traditional methods, apparently already prayed and exhausted in their contributions, are more relevant.

The initial methods of studies of labor capacity (OIT, 1996; Niebel & Freivalds, 2001) are related to two fundamental variables of unitary production capacity: number of units that can be produced in one hour and the total production fund and the normal time available to produce. The unitary production capacity can be determined from the standard time of a production unit (equation 1) or from the standard production (equation 2)

\[ C_i = \frac{FT_i}{Ni} \]  
(1)

\[ C_i = FT_i*Np_i \]  
(2)

540
Where:

\( C_i \): Real unitary capacity of the equipment in the activity \( i \).

\( FT_i \): Available normal time for the equipment in the activity \( i \).

\( N_t \): Standard time in the activity \( i \).

\( N_p \): Standard production in the activity \( i \).

The time standard is expressed in time units per unit produced, while the production standard is expressed in product units per time unit. On the other hand, the available normal time is expressed in the same unit as the standard time.

The total capacity of an activity and the operation of the process is the summary of the real unitary capacities of all the equipment that carry out the same operation (3).

\[
CT_i = Cr_i \times Ne_i
\]  

(3)

Where:

\( CT_i \): Total capacity in the activity \( i \).

\( Cr_i \): Real unitary capacity of the equipment in the activity \( i \).

\( Ne_i \): Number of equipment in the activity \( i \).

This expression is only valid when all the teams that work in the activity or operation \( i \) are the same. Otherwise, the unit capacities of all the teams are summed up (4)

\[
CT_i = \sum_{i=1}^{N} Cr_i
\]  

(4)

Where:

\( N \): Number of equipment in the activity \( i \).

When the operations are combined to generate a process formed by several homogeneous groups of equipment, the determination of the capacities of the processes must consider other factors as they can be:

i. The sequence of relationship between activities

ii. Production percentage outputs

iii. Production percentage reprocesses

In general, it is assumed that the capacity of a process is the smallest of the capacities of the homogeneous groups that integrate it, considering in the analysis of the previous variables. The previous analysis is valid whenever a single type of production volume is assumed, but when the variety of production diversifies, the analysis is insufficient since the complexity of the study is increased because each homogeneous group must assume different products with different standard times. In this context, the proposal by Fundora-Miranda (1997) is more accepted, which describes a method to determine the heterogeneous capacities for each homogeneous group of work and of the entire process from the following steps:

Step 1. Determining the Total normal time (FPT): This is the total time that could be used for manufacturing a given product. It will be conditioned by the number of days that the company decides to work on the year and the number of equipment available for each operation. It is determined by the equation 5.

\[
FPT = \text{working days per year} \times \text{number of equipment}
\]  

(5)

Step 2. Determination of allowances due to technological requirements (FRT): It is the sum of all the time that it is not possible to use the equipment for any maintenance action demands. It is determined by the equation 6.

\[
FRT = \sum \text{Maintenance times}
\]  

(6)

Step 3. Determination of the allowances due to labor regime (FRL): Refers to the total number of hours that the equipment is out of work because the personnel who use them are not available. The fundamental causes of the hours that are left to work during the day in the function of the organization of the process and the hours that are left to work in the year when the organization plans collective vacancies are considered as fundamental causes. It is determined by equation 7.
FRL = (Number of working hours per day * Number of working days + Number of working hours per day * Number of days of vacancies) * Number of equipment

(7)

Step 4. Determination of the allowances due to other causes (FOC): Corresponds to the time fund that the production capacities are affected by fortuitous causes, generally established from the historical behavior of the process as a percentage of the Total productive time. It is determined by the equation 8.

FOC = FPT * Historical percentage of loss

(8)

Step 5. Determination of the Available productive time (FPD): This is the time when each homogeneous group can work. It is determined by the equation 9.

FPD = FPT – FRT – FRL – FOC

(9)

Step 6. Determining the available productive capacities and the limit capacity. For this purpose, Table 1 is used.

<table>
<thead>
<tr>
<th>Products</th>
<th>DPi</th>
<th>Homogeneous group 1</th>
<th>Homogeneous group 2</th>
<th>Homogeneous group n</th>
<th>CPDLi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ntij</td>
<td>Qij</td>
<td>CPDij</td>
<td>Ntij</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>……</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPDj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPDj*Roj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bj</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where:

Ntij: Standard time of production of product i in the homogeneous group j

Qij: Workload of product i in the homogeneous group j

DPI: Demand for product i

CPDI: Available production capacity for product i

CPDi: Limit capacity of the available production for product i

Qj: Total workload to be assumed by the homogeneous group j

Roj: Time advantage coefficient very related to the type of production, tends to be greater in mass productions (0.96-0.85) and smaller in unitary productions (0.60 – 0.35). The unitary productions require greater adjustment time in the production changes, which causes this coefficient to be lower.

Bj is the coefficient that expresses if the homogeneous group j is able to assume the planned production.

The equations 10, 11, 12 and 13 allow the calculation of unknown parameters.

Qij = Tij * Production demand i

Qj = ∑n i=1 Tij * Di

Bj = \frac{FPDj*Roj}{Qj}

CPDij = Dpi * Bj

CPDi: will be equal to the smallest of the available capacities for the product i.

This method proposed, although it presents a relatively easy equation for calculation, possible to apply without requiring high technology, presents as a limiting factor that when there are capacity constraints that prevent generating all the required production, it proposes as a solution to distribute the available capacity evenly among the different demanded products, without considering that not all products contribute equally to the company's utilities and, therefore, it is beneficial to carry out the distribution of available capacities, prioritizing those products that may have a greater margin of contribution to the organization. The SMEs, even when high technology and specialized personnel are not available, continue to require knowledge and optimize their productive capacity. The determination of capacity is a basic requirement for these organizations to carry out the design of their business plan. This work aims
to present a proposal to improve a method to determine and optimize heterogeneous capacities, considering the contribution margins of each product.

**Proposed Methodology of the Study**

In this investigation, the methodology used was structured in three moments: development of the proposed methodology, deployment of the proposed methodology in a business context and validation of the results through the application of a linear programming method. The methodology to be developed considers the five initial steps of the existing methodology as a starting point, taking as a reference the amount of available time for each homogeneous group and introducing modifications in the specific steps that are described below.

Step 6. Sort the products by their contribution margin. Products are prioritized according to their contribution margin, giving priority to those with a greater margin. The contribution margin is determined by equation 14.

\[
MC_i = D_i \times (P_i - CVU_i) 
\]  

(14)

Where:

- \(MC_i\): Contribution margin of the product \(i\).
- \(D_i\): Demand of product \(i\).
- \(P_i\): Sales price of product \(i\).
- \(CVU_i\): Variable unit cost of product \(i\).

Step 7: Determine the normal time available for each product nomenclature and by homogeneous group. The normal time available for each product \(i\) in the homogeneous group \(j\) is determined by the equation (15)

\[
FPD_{ij} = FPD(i-1)-T_{ij} \times D_i 
\]  

(15)

Where:

- \(FPD_{ij}\): Normal time available for each product \(i\) in the homogeneous group \(j\).
- \(T_{ij}\): Operating time for a unit of product \(i\) in the homogeneous group \(j\).

Step 8. Determine the workload for each product in each homogeneous group. To determine the workload for each product in each homogeneous group, the logic summarized in Figure 1 must be followed.

![Figure 1: Workload calculation logic](image)

To calculate the capacities, it is recommended to use Table 2.
**Table 2.** Calculation of production capacity maximizing profit

<table>
<thead>
<tr>
<th>Product</th>
<th>Contribution margin</th>
<th>Demand</th>
<th>Unitary operation time by homogeneous group</th>
<th>Homogeneous group</th>
<th>Homogeneous group</th>
<th>Homogeneous group</th>
<th>Production capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td></td>
<td></td>
<td></td>
<td>i</td>
<td>...</td>
<td>J</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FPD</td>
<td>Q1</td>
<td>FPD</td>
<td>QJ</td>
</tr>
</tbody>
</table>

The production capacity of each product will be the smallest of the product capacities among the different homogeneous groups.

**Results and discussion**

**Phase 1. Exploratory**

In this phase, the conditions for the practical development of the research were prepared, achieving the selection of the work team, the training and the communication of the actions to be developed to the areas involved.

To validate the proposed methodology, an entity with low level of complexity was selected with only three products and five homogeneous groups of work. It was applied in a Digital Printing, which was created in the City of Santo Domingo de los Tsáchilas, in order to respond to the unsatisfied demand of this Ecuadorian province.

The products that are produced are: Labels and Stickers, with a demand of 89,200 units per year; Triptyches, with a demand of 10,984 units per year; and Gigantographies, with a demand of 1,056 units per year.

Five different homogeneous groups are used for the production process, these are: Design, Printing, Drying, Cutting and Packing. The company works 305 days a year, one work shift a day, and 32 hours are allocated a year for equipment maintenance activities. Massive vacations take place during 15 days of the year. Losses of time due to other causes are established by historical data. The data on the amount of available time of each group are shown in Table 3.

**Table 3: Normal times by Homogeneous group**

<table>
<thead>
<tr>
<th>Homogeneous group</th>
<th>Number of equipment</th>
<th>FPT</th>
<th>FRT</th>
<th>FRL</th>
<th>FOC</th>
<th>FPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>2</td>
<td>14640</td>
<td>32</td>
<td>9390</td>
<td>756</td>
<td>4462</td>
</tr>
<tr>
<td>Printing</td>
<td>2</td>
<td>14640</td>
<td>32</td>
<td>9390</td>
<td>112</td>
<td>5106</td>
</tr>
<tr>
<td>Drying</td>
<td>2</td>
<td>14640</td>
<td>32</td>
<td>9390</td>
<td>0</td>
<td>5218</td>
</tr>
<tr>
<td>Cutting</td>
<td>2</td>
<td>14640</td>
<td>32</td>
<td>9390</td>
<td>112</td>
<td>5106</td>
</tr>
<tr>
<td>Packing</td>
<td>2</td>
<td>14640</td>
<td>32</td>
<td>9390</td>
<td>756</td>
<td>4462</td>
</tr>
</tbody>
</table>

*Note:* The amount of available time are expressed in hours per year.

Table 4 shows the standard time data for each product in each homogeneous group and table 5 summarizes the calculation of normal times and production capacities.

**Table 4: Standard time for products by homogeneous group**

<table>
<thead>
<tr>
<th>Product</th>
<th>Standard time for the product in the homogeneous group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design</td>
</tr>
<tr>
<td>Triptyches</td>
<td>0.057</td>
</tr>
<tr>
<td>Gigantographies</td>
<td>0.016</td>
</tr>
<tr>
<td>Labels and Stickers</td>
<td>0.040</td>
</tr>
</tbody>
</table>

As can be seen in Table 5, priority is given to the production of those products that generate greater profit margins, with the available normal time, it is not possible to satisfy the demand for the three types of existing products.
### Table 5: Calculation of normal times and available capacities by products

<table>
<thead>
<tr>
<th>Products</th>
<th>Design</th>
<th>Printing</th>
<th>Drying</th>
<th>Cutting</th>
<th>Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profits margin</td>
<td>4462</td>
<td>5106</td>
<td>5218</td>
<td>5106</td>
<td>4462</td>
</tr>
<tr>
<td>Production capacity</td>
<td>PP</td>
<td>PP</td>
<td>PP</td>
<td>PP</td>
<td>PP</td>
</tr>
<tr>
<td>Note: PP. Production plan.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 6: Comparison of capacity analysis methods

<table>
<thead>
<tr>
<th>Products</th>
<th>Traditional method</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Production capacity</td>
<td>Profit</td>
</tr>
<tr>
<td>Triptyches</td>
<td>4004</td>
<td>5 365.36</td>
</tr>
<tr>
<td>Gigantographies</td>
<td>385</td>
<td>1 732.50</td>
</tr>
<tr>
<td>Labels and stickers</td>
<td>32523</td>
<td>21 465.18</td>
</tr>
<tr>
<td>Total</td>
<td>28 563.04</td>
<td>35 577.20</td>
</tr>
</tbody>
</table>

From the analysis, it appears that the traditional method to achieve an equitable distribution of the limiting capacity for all the products that are designed to produce, without considering the contribution margin of each individual, delivers results that can be optimized with the application of the proposed method.

Additionally, as a second form of validation, linear programming and the application of the Simplex method were used to solve the proposed problem. The modeling of the problem is presented below.

**Purpose Function:** Max $Z = 1.34X_1 + 4.5X_2 + 0.66X_3$  \hspace{1cm} (16)

**Constraints**

\begin{align*}
0.057X_1 + 0.016X_2 + 0.04X_3 & \leq 4462 \\
0.09X_1 + 0.2X_2 + 0.033X_3 & = 5106 \\
0.05X_1 + 0.1X_2 + 0.04X_3 & \leq 5218 \\
0.04X_1 + 0.1X_2 + 0.04X_3 & \leq 5106 \\
0.13X_1 + 0.1X_2 + 0.12X_3 & \leq 4462 \\
X_1 & \leq 10984 \\
X_2 & \leq 1056
\end{align*}
For the modelling, the profit margins per product for the purpose function, the time norms for each product and the productive funds available for each homogeneous group are assumed, in addition that no product must be produced over the contracted production for each product. For the solution of the case, it was resorted to the use of a program of easy understanding and access as QM for Window; through this, the results shown in figures 2 and 3 were obtained. As the results obtained in this way can be appreciated, they correspond to those obtained with the proposed methodology.

Conclusions

In addition to the development of advanced techniques of mathematical analysis algorithms to optimize productive processes, supported by computer advances, demonstrating significant advances, these results are always within reach of most entrepreneurs who are in front of micro, small and medium-sized companies in the majority of world economies, where these companies represent a highly significant percentage. The proposed methodology is easy to apply for companies that do not have high technology or a specialized staff for the application of advanced mathematics techniques.

The proposed methodology additionally introduces the analysis of the utility margins per product in the process of analyzing the capacities, allowing to optimize the performance. The analyzes carried out show that the results obtained ensure benefits superior to those allowed by the traditional methodology and of the same quality as those obtained through the application of linear programming as a method to optimize capacities.

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Author Contributions: Conceptualization, Methodology, Data Collection, Formal Analysis, Writing—Original Draft Preparation, Writing—Review And Editing by authors with equal participation. All authors have read and agreed to the published the final version of the manuscript.
**Institutional Review Board Statement:** Ethical review and approval were waived for this study, due to that the research does not deal with vulnerable groups or sensitive issues.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

**Conflicts of Interest:** The authors declare no conflict of interest.

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